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Staircase - Dimensions of Stair Steps and their Deviations of Geometrical Accuracy

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Abstract. The staircase is an integral part of most buildings. It is subject to the same technological principles and constraints as for other building structures. This design must meet basic technical requirements, including stairway safety. The requirements for selected geometric parameters of stair steps are defined in Czech technical standards and regulations. Generally, the requirements of these regulations are summarized as follows: "All the stairs to the walking line in one flight must have the same height and width and must be horizontal, without inclination in the transverse or longitudinal direction." This provision prescribes mainly design requirements of stairs, while the requirements for as-built stairs are not taken into account. This is evidenced by the fact that in the Czech technical regulations and standards the geometrical accuracy of the as-built stair steps is not specified. Deviations from the geometrical accuracy of stair steps are technologically inevitable. But in practice in the Czech Republic, we encounter situations where builders use the formulation of technical standards and binding regulations to their advantage and refuse to take over the completed staircase. As an argument, they use the formula stated in the above-mentioned regulations. Based on this wording, they require the completed stair steps to have zero geometric accuracy deviations, which are technologically unfeasible. The only way to prevent these attempts is to revise existing regulations to complement the design requirements, including allowable deviations of the geometric accuracy of stair steps. Geometrical tolerances must be determined to take account of the technological possibilities of the construction and to assure safe movement on the staircase. Measurements of dimensions (rise and going) of the as-built stair steps (rise and going) were executed. The results of the measurements were compared with the requirements of the British and German technical standards for staircases. Measurements made in buildings in the Czech Republic showed that about 95% of the measured deviations of step rise and going were not more than 5 mm, which complied with the requirements of the German technical standard.

1. Introduction

In the Czech Republic, the requirements for staircase geometry are set out in the following documents:

- Decree No. 268/2009 Coll., Technical Requirements for Buildings as amended
- Regulation No. 10/2016 Coll. laying down general requirements for land use and technical requirements for buildings in the Capital City of Prague (Prague Building Regulations hereinafter PBR)
- ČSN 73 4130 - Stairs and sloping ramps - Basic requirements.

In these regulations and technical standards requirements are set for the dimensions of rise and going of stair steps. None of these standards specifies requirements of as-built staircases. Especially, there are no geometrical tolerances specified for the rise and going of the stair steps, which is a significant complication for the construction contractor.

The clients use this in their favour and refuse to take over the completed staircase from the construction contractor. As an argument, they use the formula set in the above-mentioned regulations that states: *"All stair steps on the walking line in one staircase must have the same dimensions of rise and going and must be flat without a gradient in the transverse or longitudinal direction."* Based on this formulation, clients require the completed steps to have zero geometric accuracy deviations, which are technologically unfeasible.

The technical standards, which do not solve the geometrical precision of the as-built stair steps, do not explain the situation either. The aim should be to modify staircase geometry requirements to take account of the technological possibilities of the construction technologies while maintaining maximum stairway safety.

2. Stairway safety

Staircase dimensions should be designed with respect to stairway safety. It is important to choose the right height (rise) and width (going) dimensions of stair steps to minimize the risk of slipping or tripping over the step see figure 1.

In the Czech Republic, no study on stairway safety has been published to address the risk of injury due to the dimensions, variability and surface treatment of staircases. For example, in the UK, this issue was solved in detail on the basis of research. Research focused primarily on how the width of stair steps influences the position of the foot at the edge of the stairs. The stairway safety is closely related to geometrical tolerances of the staircase steps (especially the successive steps).

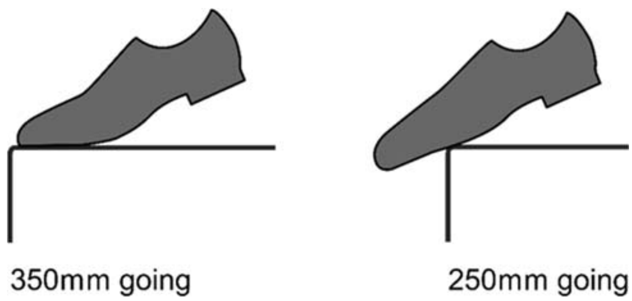

Figure 1. Foot position at the edge of the stairs (considered for shoe size 9) [1]

Within the stairwell, there will always be some deviations in the height and width of stair steps resulting from the used construction technology. Variation between adjacent steps can have the effect of changing the amount of the foot that hangs over the nosing. The size of this effect is related to the difference in the rise or going and would be most significant during descent where a step with smaller going immediately follows a step with a larger going. Depending on the size of the average going and the deviation, a variability between steps can increase the risk of a slip on the smaller step to more than the risk associated with the rest of the flight. [2]

Due to stairway safety, it is better to design stairways with greater going (lower risk of slipping) and lower rise (lower risk of tripping). One of the research results developed the risk algorithm, depending on the going dimension and the frequency of stairway use see figure 2.

Going (mm)	Average time between occurrences of a large overstep *			
	5 uses a day	25 uses a day	100 uses a day	2,000 uses a day
225	4 years	298 days	75 days	4 days
250	11 years	2 years	198 days	10 days
275	145 years	29 years	7 years	133 days
300	>1,000 years	>1,000 years	>1,000 years	73 years
325	>100,000 years	>1,000 years	>1,000 years	568 years

* Note: An overstep is a misstep where a large proportion (50%) of the foot is hanging over the edge of the nosing in descent. Undetected variations in step dimensions can also cause stumbles in ascent. IP 15/03

Figure 2. The risk of falling on staircase with 14 steps [1]

For example, for a staircase with a step going of 250 mm and a daily passage of about 100 people, there is a risk of falling every 198 days.

3. Requirements of Czech and foreign regulations and technical standards

The most important parameters are the rise and going of stair steps and their geometrical tolerances. The values required by Czech regulations and foreign standards were compared. For comparison the following foreign technical standards were considered:

- DIN 18 065 - Stairs in buildings –Terminology, measuring rules, main dimensions
- BS 5395-1 - Stairs. Code of practice for the design of stairs with straight flights and winders.

Table 1. Comparison of required dimensions of public stair steps (in mm) [2,3,4,5]

Technical standard, Regulation	*Going width*		*Tread width*		*Rise height*		*Deviations*
	Min.	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	
ČSN	210	-	250	-	150[a]	180[a]	NDF
PBR	210	-	250	-	-	-	NDF
DIN	260	370	-	-	140[b]	190[b]	± 5 mm[c]
BS	300	450	-	-	150	180	1,5 % of the going 1 % of the rise

NDF – not defined

[a] This is only the optimal recommended height. The height-to-width ratio of the stair steps is determined by the formula 2h + b = 630, where h is the height of the step and b the step width.

[b] The height-to-width ratio of the stair steps shall be determined by the formula 2h + b, where h is the height of the step and b the step width. The resulting value must be in the range of 590 to 650.

[c] with the difference in the rise of the two consecutive steps max. 5 mm

Table 2. Comparison of required dimensions of private stair steps (in mm)

Technical standard, Regulation	*Going width*		*Tread width*		*Rise height*		*Deviations*
	Min.	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	
ČSN	210	-	250	-	150[a]	180[a]	NDF
PBR	180	-	225	-	-	-	NDF
DIN	230	370	-	-	140[b]	200[b]	± 5 mm[c]
BS	250	400	-	-	150	200	1 % of the going and rise

NDF – not defined
[a] This is only the optimal recommended height. The height-to-width ratio of the stair steps is determined by the formula 2h + b = 630, where h is the height of the step and b the step width.
[b] The height-to-width ratio of the stair steps shall be determined by the formula 2h + b, where h is the height of the step and b the step width. The resulting value must be in the range of 590 to 650.
[c] with the difference in the rise of the two consecutive steps max. 5 mm

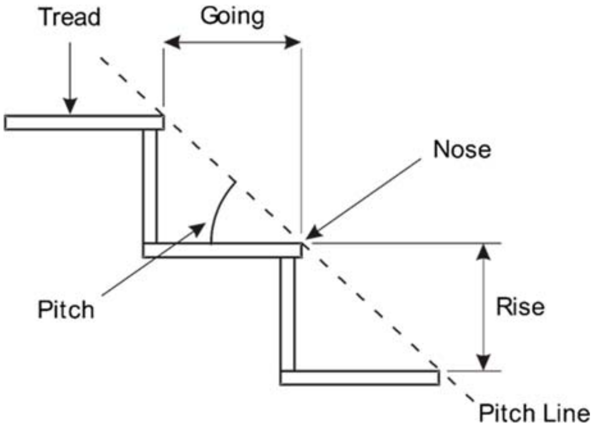

Figure 3. Staircase terminology [1]

It is clear from the table 1 and table 2 that the requirements of the Czech regulations and the foreign standards differ significantly. In all cases, the Czech regulations require smaller dimensions of step going than the foreign standards, while not specifying the step rise or geometrical tolerances. In addition, the Czech regulations specify the tread width. The difference between going and tread is shown in figure 3.

4. Deviations of the stair steps set out in the foreign standards

The German standard DIN 18 065 requires the geometrical accuracy of the stair step as described below

- Rise and going of built step may vary by ± 5 mm from the designed value, with the rise difference between the two consecutive steps being max. 5 mm.
- In the case of residential buildings with a maximum of two floors (family house), the rise of the entrance and exit built steps can differ by no more than ± 15 mm from the proposed value. Other requirements are the same as in the previous bullet.

British Standard BS 5395-1 has a deviations set relatively strictly. Originally, before the 2010 change, the deviations were set as well as those in the German standard. The requirements for stairway safety have been taken into account as part of the amendment to the standard. The new requirements are based on the results of the UK research. The standard admits that deviations can reach even higher values, but in this case, it is recommended to design stair steps with a larger width to reduce the risk of falling.

5. Evaluation of measurements of as-built stair steps

Stairways in public buildings and the main staircase in apartment buildings were measured. The going of the measured steps was between 270 and 300 mm, rise between 153 and 167 mm. The structure of staircases was monolithic or prefabricated. Surface treatment was surface treated concrete or ceramic tile. Measurement of the dimensions was performed on the walking line, using a framing square and a measuring tape. Deviations of rise, going, and of the rise of two consecutive steps were evaluated.

Table 3. Deviation of rise

Deviation [mm]	*0*	*-1*	*1*	*-2*	*2*	*-3*	*3*	*-4*	*4*	*-5*	*5*
Frequency	92	105	70	38	88	55	71	55	43	28	28
Cumul. %	12.80	27.40	37.13	42.42	54.66	62.31	72.18	79.83	85.81	89.71	93.60
Deviation [mm]	-6	6	-7	7	-8	8	-9	9	-10	10	Other
Frequency	13	9	0	4	2	0	3	1	1	2	11
Cumul. %	95.41	96.66	96.66	97.22	97.50	97.50	97.91	98.05	98.19	98.47	100

Table 4. Deviation of going

Deviation [mm]	*0*	*-1*	*1*	*-2*	*2*	*-3*	*3*	*-4*	*4*	*-5*	*5*
Frequency	146	168	72	92	24	33	4	49	2	18	4
Cumul. %	22.57	48.53	59.66	73.88	77.59	82.69	83.31	90.88	91.19	93.97	94.59
Deviation [mm]	*-6*	*6*	*-7*	*7*	*-8*	*8*	*-9*	*9*	*-10*	*10*	*Other*
Frequency	15	4	7	1	3	0	1	0	3	0	1
Cumul. %	96.91	97.53	98.61	98.76	99.23	99.23	99.38	99.38	99.85	99.85	100

Table 5. Deviation of the rise of two consecutive steps

Deviation [mm]	*0*	*-1*	*1*	*-2*	*2*	*-3*	*3*	*-4*	*4*	*-5*	*5*
Frequency	169	118	102	45	59	28	30	24	18	15	12
Cumul. %	26.12	44.36	60.12	67.08	76.20	80.53	85.16	88.87	91.65	93.97	95.83
Deviation [mm]	*-6*	*6*	*-7*	*7*	*-8*	*8*	*-9*	*9*	*-10*	*10*	*Other*
Frequency	5	2	1	3	6	2	0	2	1	1	4
Cumul. %	96.60	96.91	97.06	97.53	98.45	98.76	98.76	99.07	99.23	99.38	100

6. Measurement evaluation and results

All measurements show that for all of considered parameters, deviations of up to 5mm were achieved with approximately 95% accuracy. For comparison, the geometric accuracy evaluation according to British Standard BS 5395-1 is shown in the table below.

Table 6. Geometric evaluation of measured deviations according to BS 5395-1

	Deviation of rise	*Deviation of going*
YES	38.66 %	91.19 %
NO	61.34 %	8.81 %

If the measured values were compared with the requirements of the British Standard, the results would always depend on the proposed dimensions of the stair step.

From the comparison, it could be seen that in the case of going deviation a high percentage of measurements achieved the required 1.5% deviation of the design value. The percentage of deviations of going that met the desired value would be reduced or enlarged depending on the design value. Compliance with this requirement would already be very problematic because the tolerance of 1% of the designed value is very strict.

7. Conclusion

The minimum requirements for the proposed staircase dimensions were set very low in the Czech technical standards compared to the international standards and compared to the stairway safety requirements. This may be due to the fact, that the surveys on stairway safety showed that stair flights with wider going (and lower rise) were less likely to fall.

The measurements of the as-built dimensions (rise and going) of stair steps indicated that 95% of the deviations could be kept below 5 mm of the design dimensions. The deviations of up to 3 mm represented roughly 72 % to 85 %. The evaluation showed that most of the measured deviations would be able to meet the requirements of the German DIN standard. On the contrary, the requirements of the British Standard BS were much stricter, and the tolerances of the rise height, could only be satisfied to a very limited extent.

There was no description of the method for measuring stair steps dimensions in any technical regulation.

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